

PILOT- AND FULL-SCALE DEMONSTRATION OF ADVANCED MERCURY CONTROL TECHNOLOGIES FOR LIGNITE-FIRED POWER PLANTS

Quarterly Report

(for the Period of June 30, 2003 – September 30, 2003)

Prepared for:

AAD Document Control

National Energy Technology Laboratory
PO Box 10940, MS 921-107
Pittsburgh, PA 15236-0940

Cooperative Agreement No. DE-FC26-03NT41897
Performance Monitor: Andrew O’Palko

Prepared by:

Steven A. Benson

Energy & Environmental Research Center
University of North Dakota
Box 9018
Grand Forks, ND 58202-9018

November 2003

DOE DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government, nor any agency thereof, nor any of their employees makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

This report is available to the public from the National Technical Information Service, U.S. Department of Commerce, 5285 Port Royal Road, Springfield, VA 22161; phone orders accepted at (703) 487-4650.

ACKNOWLEDGMENT

This report was prepared with the support of the U.S. Department of Energy (DOE) National Energy Technology Laboratory Cooperative Agreement No. DE-FC26-03NT41897. However, any opinions, findings, conclusions, or recommendations expressed herein are those of the authors(s) and do not necessarily reflect the views of DOE.

EERC DISCLAIMER

LEGAL NOTICE This research report was prepared by the Energy & Environmental Research Center (EERC), an agency of the University of North Dakota, as an account of work sponsored by DOE. Because of the research nature of the work performed, neither the EERC nor any of its employees makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement or recommendation by the EERC.

TABLE OF CONTENTS

LIST OF FIGURES	iii
LIST OF TABLES	iii
INTRODUCTION	1
WORK PLAN	1
BACKGROUND	2
Mercury Control Options	2
Mercury Oxidation	5
EXPERIMENTAL	7
Objective and Goals	7
PLANNED SCOPE OF WORK	7
Task 1 – Mercury Control Enhancement for Unscrubbed Systems Equipped with ESPs	7
Task 2 – Mercury Oxidation Upstream of Wet and Dry Scrubbers	8
Task 2.1 – Elemental Mercury Oxidation Additives	8
Task 2.2 – Sorbent Injection	8
Task 3 – Field Tests to Determine Impacts of Oxidizing Agents on Mercury Speciation	8
Task 3.1 – Impacts of Cofiring on Tire-Derived Fuels	8
Task 3.2 – Impacts of Oxidation Catalysts – Coyote Station Slipstream Testing	9
Task 4 – Particulate and Mercury Control for ND Lignites Using the <i>Advanced Hybrid</i> TM Technology	9
Task 5 – Field Testing of Sorbents and Gore Technology	9
RESULTS AND DISCUSSION	10
Task 1 – Mercury Control Enhancement for Unscrubbed Systems Equipped with ESPs ..	10
Task 2 – Mercury Oxidation Upstream of Wet and Dry Scrubbers	10
Task 2.1 – Elemental Mercury Oxidation Additives	10
Task 2.2 – Sorbent Injection	11
Task 3 – Field Tests to Determine Impacts of Oxidizing Agents on Mercury Speciation	11
Task 3.1 – Impacts of Cofiring on Tire-Derived Fuels	11
Task 3.2 – Impacts of Oxidation Catalysts – Coyote Station Slipstream Testing	11

Continued. . .

TABLE OF CONTENTS (continued)

Task 4 – Particulate and Mercury Control for ND Lignites Using the AH Technology	12
Task 5 – Field Testing of Sorbents and Gore Technology.....	13
FUTURE WORK – NEXT QUARTER	18
REFERENCES	20
PRELIMINARY RESULTS AND DISCUSSION.....	APPENDIX A

LIST OF FIGURES

1	Pilot-scale ESP (8) and full-scale COHPAC and ESP (9) Hg removal efficiencies as a function of activated carbon injection rate	3
2	Pilot-scale ESP (8) and full-scale COHPAC and ESP (9) Hg removal efficiencies as a function of activated carbon injection rate.....	4
3	Hg emissions for activated carbon injection combined with additives.....	6
4	Mercury emission at the ESP outlet with sorbent and additive addition	12
5	Baghouse chamber and support structure	14
6	Baghouse top and exhaust header	15
7	Baghouse extension showing inlet ports.....	15
8	Completed baghouse.....	16
9	Milestone chart.....	19

LIST OF TABLES

1	Test Matrix of Mercury Control for an Unscrubbed System Equipped with ESP.....	11
2	Test Matrix of Mercury Control for a Retrofit <i>Advanced Hybrid</i> TM Filter System	13

PILOT- AND FULL-SCALE DEMONSTRATION OF ADVANCED MERCURY CONTROL TECHNOLOGIES FOR LIGNITE-FIRED POWER PLANTS

INTRODUCTION

North Dakota (ND) lignite-fired power plants have shown a limited ability to control mercury emissions in currently installed electrostatic precipitators (ESPs), dry scrubbers, and wet scrubbers (1). This low level of control can be attributed to the high proportions of Hg^0 present in the flue gas. Speciation of Hg in flue gases analyzed as part of the U.S. Environmental Protection Agency (EPA) information collection request (ICR) for Hg data showed that Hg^0 ranged from 56% to 96% and oxidized mercury ranged from 4% to 44%. The Hg emitted from power plants firing ND lignites ranged from 45% to 91% of the total Hg, with the emitted Hg being greater than 85% elemental. The higher levels of oxidized mercury were only found in a fluidized-bed combustion system. Typically, the form of Hg in the pulverized and cyclone-fired units was dominated by Hg^0 at greater than 85%, and the average amount of Hg^0 emitted from ND power plants was 6.7 lb/TBtu (1, 2).

The overall objective of this Energy & Environmental Research Center (EERC) project is to develop and evaluate advanced and innovative concepts for controlling Hg emissions from ND lignite-fired power plants by 50% to 90% at costs of one-half to three-fourths of current estimated costs. The specific objectives are focused on determining the feasibility of the following technologies: Hg oxidation for increased Hg capture in wet and dry scrubbers, incorporation of additives and technologies that enhance Hg sorbent effectiveness in ESPs and baghouses, the use of amended silicates in lignite-derived flue gases for Hg capture, and the use of Hg adsorbents within a baghouse. The scientific approach to solving the problems associated with controlling Hg emissions from lignite-fired power plants involves conducting testing of these processes and technologies that have shown promise on a bench, pilot, or field scale: 1) activated carbon injection (ACI) upstream of an ESP combined with sorbent enhancement, 2) Hg oxidation and control using wet and dry scrubbers, 3) enhanced oxidation at a full-scale power plant using tire-derived fuel (TDF) and oxidizing catalysts, and 4) testing of Hg control technologies in the *Advanced Hybrid*TM filter insert.

WORK PLAN

The work plan for this proposed project consists of six tasks outlined as follows:

- Task 1 – Mercury Control Enhancement for Unscrubbed Systems Equipped with ESPs
- Task 2 – Mercury Oxidation Upstream of Wet and Dry Scrubbers
- Task 3 – Field Tests to Determine Impacts of Oxidizing Agents on Mercury Speciation
- Task 4 – Particulate and Mercury Control for North Dakota Lignites Using the *Advanced Hybrid*TM Filter Technology

- Task 5 – Field Testing of Sorbents and Gore Technology
- Task 6 – Project Reporting and Management

BACKGROUND

ND lignite-fired power plants have shown a limited ability to control Hg emissions in currently installed ESPs, dry scrubbers, and wet scrubbers (1). This low level of control can be attributed to the high proportions of Hg^0 present in the flue gas. Speciation of Hg in flue gases analyzed as part of the EPA ICR for Hg data showed that Hg^0 ranged from 56% to 96% and the oxidized mercury ranged from 4% to 44%. The Hg emitted from power plants firing ND lignites ranged from 45% to 91% of the total Hg, with the emitted Hg being greater than 85% elemental. The higher levels of oxidized mercury were only found in a fluidized-bed combustion system. Typically, the form of Hg in the pulverized and cyclone-fired units was dominated by Hg^0 , being greater than 85% elemental, and the average emitted from ND power plants was 6.7 lb/TBtu (1, 2).

The composition of a coal has a major impact on the quantity and form of Hg in the flue gas and, as a result, on the ability of air pollution control devices (APCDs) to remove Hg from flue gas. In general, ND lignitic coals are unique because of a highly variable ash content, ash that is rich in alkali and alkaline-earth-rich elements, high oxygen levels, high-moisture levels, and low chlorine content. Experimental results indicate that low-chlorine (<50-ppm) coal combustion flue gases (typical of ND lignite) contain predominantly Hg^0 , which is substantially more difficult to remove than Hg^{2+} (3). The generally high calcium contents of lignite coals may reduce the oxidizing effect of the already low chlorine content by reactively scavenging chlorine species (Cl , HCl , and Cl_2) from the combustion flue gas. The level of chlorine in flue gases of recently tested ND and Saskatchewan lignites ranged from 2.6 to 3.4 ppmv, with chlorine contents ranging from 11 to 18 ppmw in the coal on a dry basis, respectively.

Mercury Control Options

The technologies utilized for the control of Hg will ultimately depend upon the EPA-mandated emission limits. Options being investigated have the potential to attain over 90% control of Hg emissions. The Hg control strategies at ND lignite-fired power plants involve first the enhancement of existing control technologies and second investigation and development of new control technologies. The strategies include sorbent injection with and without enhancements upstream of an ESP or fabric filter (FF) and Hg oxidation upstream of a wet or dry flue gas desulfurization system (FGD). The new technologies being investigated include Hg capture using the EERC's advanced hybrid particulate collector (AHPC) or the *Advanced Hybrid*TM gold-coated materials, baghouse inserts, and carbon beds (4).

Sorbent injection for removing Hg involves adsorption of Hg species by a solid sorbent injected upstream of a particulate control device such as a FF (baghouse) or ESP. Many potential Hg sorbents have been evaluated (4). These evaluations have demonstrated that the chemical speciation of Hg controls its capture mechanism and ultimate environmental fate.

Activated carbon injection is the most mature technology available for Hg control. Activated carbons have the potential to effectively sorb Hg^0 and Hg^{2+} but depend upon the carbon characteristics and flue gas composition (4). Most activated carbon research has been performed in fixed-bed reactors that simulate relatively long-residence-time (gas–solid contact times of minutes or hours) Hg capture by a FF filter cake (5–7). However, it is important to investigate short-residence-time (seconds) in-flight capture of Hg^0 because most of the coal-burning boilers in the United States employ cold-side ESPs for controlling particulate matter emissions. The projected annual cost for activated carbon adsorption of Hg in a duct injection system is significant. Carbon-to-mercury weight ratios of 3000:18,000 (lb carbon injected/lb Hg in flue gas) have been estimated to achieve 90% Hg removal from a coal combustion flue gas containing $10 \mu\text{g}/\text{Nm}^3$ of Hg (8). More efficient carbon-based sorbents are required to enable lower carbon-to-mercury weight ratios to be used, thus reducing the costs. Recent testing conducted at the EERC, as shown in Figures 1 and 2, illustrates the effectiveness of sorbents injected upstream of the ESP and baghouse, respectively.

EERC pilot-scale ESP and ESP–FF Hg removal efficiencies for the Fort Union lignite coals from Saskatchewan and ND (Poplar River and Freedom coals) flue gases are compared in Figures 1 and 2 to those obtained at full-scale utility boilers, while injecting activated carbons into a bituminous coal combustion flue gas upstream of a compact hybrid particulate collector (COHPAC) (pulse-jet FF) and into bituminous and Powder River Basin (PRB) subbituminous coal combustion flue gases upstream of an ESP. Coal type (i.e., composition) is an important

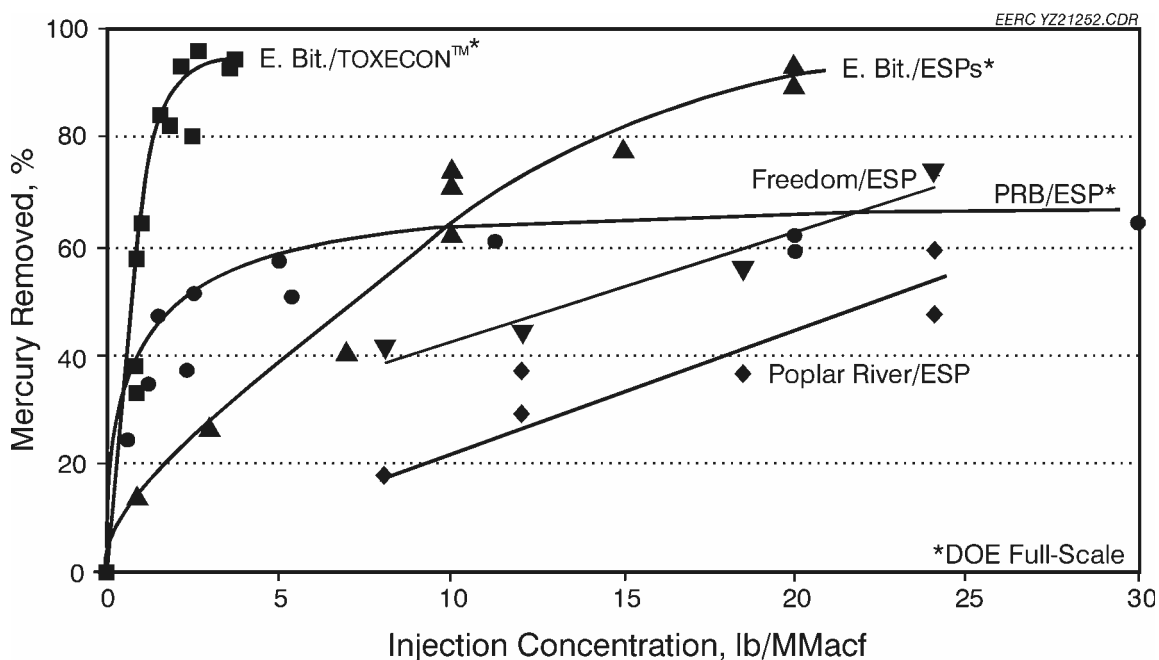


Figure 1. Pilot-scale ESP (8) and full-scale COHPAC and ESP (9) Hg removal efficiencies as a function of activated carbon injection rate.

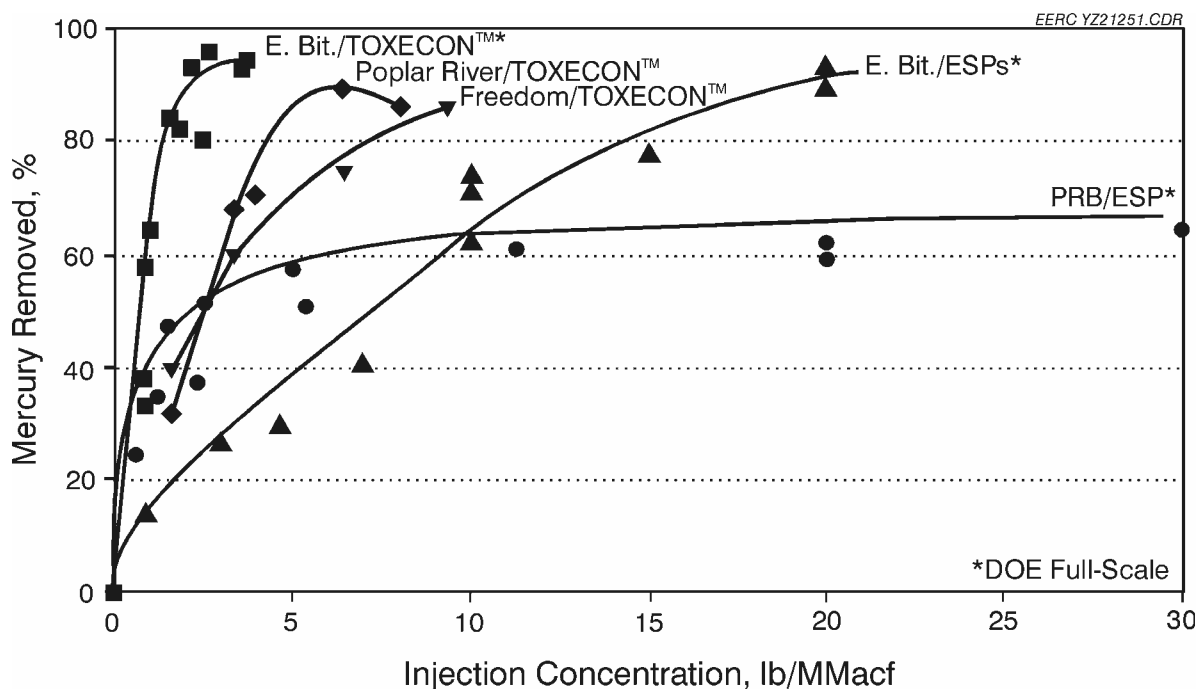


Figure 2. Pilot-scale ESP–FF (8) and full-scale COHPAC and ESP (9) Hg removal efficiencies as a function of activated carbon injection rate.

parameter that affects the Hg removal efficiency of a control device. During the pilot-scale lignite and utility-scale eastern bituminous coal tests, Hg removal efficiency increased with increasing activated carbon injection rates. Conversely, Hg removal efficiency was never greater than 70%, regardless of the activated carbon injection rate into the PRB subbituminous coal combustion flue gas. This limitation is probably caused by the low amount of acidic flue gas constituents, such as HCl, that promote Hg-activated carbon reactivity.

Testing conducted at lignite-fired power plants equipped with a spray dryer baghouse firing Fort Union lignite indicated poor performance of conventional ACI to control Hg (10). The results indicate control efficiency of less than 35% for DARCO® FGD and lignite-activated carbon (LAC). The poor results are due to the low-acid-gas-containing flue gas and the high proportion of Hg^0 in the flue gas stream. The iodine-impregnated activated carbon (IAC) showed approximately 90% control.

Researchers at the EERC and elsewhere are striving to attain a better understanding of Hg species reactions on activated carbon surfaces in order to produce more efficient sorbents. Functional groups containing inorganic elements such as chlorine or sulfur appear to have a significant role in bonding Hg (11–13). Recently, detailed analysis of sorbents derived from lignites exposed to flue gas and Hg^0 indicated the key species impacting oxidation and retention of Hg on the surface of the carbon contain chlorine and sulfur (14, 15). The chlorine reacts to form organically associated chlorine on the surface, and it appears that the organically associated chlorine on the carbon is the key site responsible for bonding with the Hg^{2+} species.

Amended silicate injection shows promise in controlling Hg emissions at coal-fired power plants (16). The amended silicates have shown improvement factors of 1.5 to 2 in controlling Hg emissions over activated carbon from subbituminous coal testing in a pilot-scale test. The amended silicates have not been tested using ND lignites.

Mercury Oxidation

Mercury oxidation technologies being investigated for Fort Union lignites include catalysts, chemical agents, and cofiring materials. The catalysts that have been tested include a selective catalytic reduction (SCR) catalyst for NO_x reduction, noble metal-impregnated catalysts, and oxide-impregnated catalysts. The chemical agents include chlorine-containing salts and cofiring fuels that contain oxidizing agents (10).

SCR catalysts were tested for their ability to oxidize Hg; results were mixed. Mercury speciation sampling conducted upstream and downstream of SCR catalysts at power plants that fire bituminous and subbituminous coals (17) showed evidence of mercury oxidation across SCR catalysts when firing bituminous coals. However, when firing subbituminous coal, the results indicate limited oxidation, and more testing needs to be conducted on low-rank coals. The ability of the SCR system to contribute to oxidation appears to be coal-specific and is related to the chloride, sulfur, and calcium content of the coal as well as temperature and specific operation of the SCR catalyst including space velocity.

Mercury oxidation catalysts have shown high potential to oxidize Hg⁰. Results in testing a slipstream at a ND power plant indicated over 80% conversion to oxidized mercury for periods of up to 6 months (10). Tests were also conducted using iron oxides and chromium, with little success of oxidation. Galbreath and others (18) have conducted short-term pilot-scale testing with maghemite (γ-Fe₂O₃) additions and were able to transform about 30% of the Hg⁰ in ND lignite combustion flue gases to Hg²⁺ and/or Hg(p) and, with an injection of a small amount of HCl (100 ppmv), nearly all of the Hg⁰ to Hg²⁺. Theoretically, the use of chloride compounds to oxidize Hg⁰ to Hg²⁺ makes sense. The evidence includes chemical kinetic modeling of bench-scale test results indicating that the introduction of chloride compounds into the high-temperature furnace region will most likely result in the production of atomic chlorine and/or molecular chlorine, which are generally thought to be the dominant Hg⁰ reactants in coal combustion flue gases (4).

Fuel additives for mercury oxidation and sorbent enhancement have recently been tested at the EERC. The results of the addition of materials with coal at very low levels along with the ACI upstream of an ESP–FF, *Advanced Hybrid*[™], and ESP only are illustrated in Figure 3. The first part of the figure shows the baseline data for Hg emissions ranging from 9 to 12 μg/Nm³, with 80% to 90% of the Hg in the elemental form. The second case is activated carbon injection followed by the addition of Additive 2, showing a reduction in Hg emissions to 90% removal. The third case is the *Advanced Hybrid*[™] filter, which produced nearly 90% control efficiency. The final ESP-only case also indicated up to 90% control. The control efficiency for the ESP-only case showed significant potential improvement over past results obtained with the ESP-only illustrated in Figure 1. This technology also has the potential to improve dry FGD baghouse control efficiency.

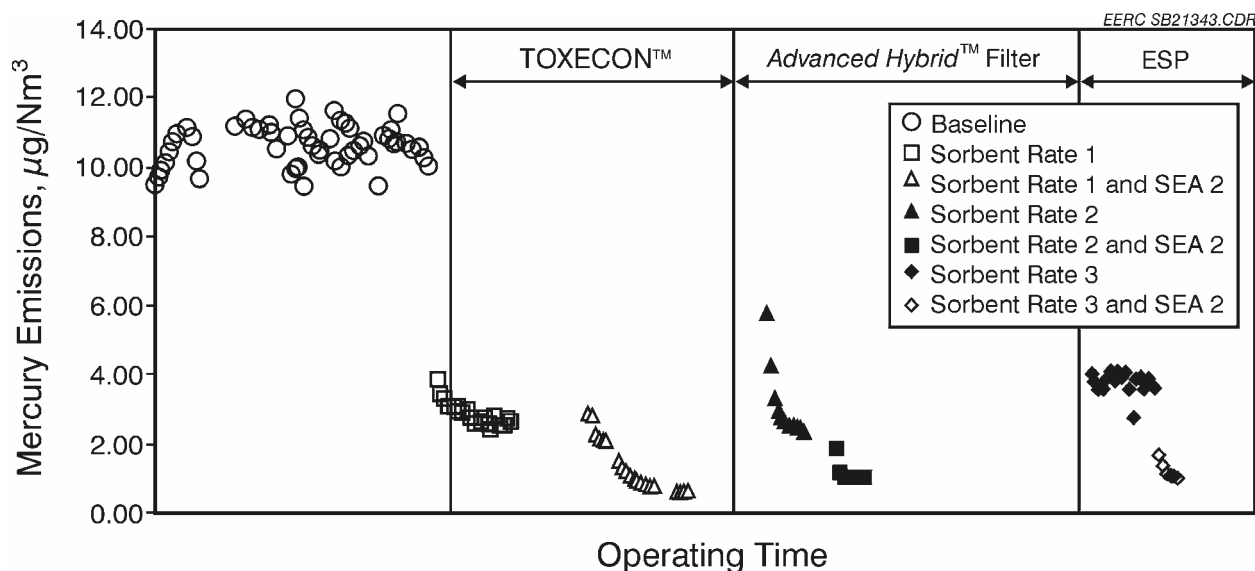


Figure 3. Hg emissions for activated carbon injection combined with additives.

Sorbent enhancement technologies have also been investigated by ALSTOM. The sorbent preparation system enhances sorbent performance by changing the physical and chemical nature of the sorbent. The enhancement is expected to be applicable to a significant number of sorbents currently utilized for Hg control. The potential for sorbent enhancement has shown an increase from 68% to over 90% capture of Hg. These tests evaluated the performance of baseline and enhanced sorbents in entrained flow. Sorbents were injected in a duct with synthetic flue gas followed by an ESP.

Cofiring TDF at Otter Tail Power's Big Stone Plant has been suspected to contribute to very high reactivity of Hg with fly ash and also with carbon sorbents while firing a low-chlorine PRB coal (19). At periods of operation that coincide with cofiring TDF, enhanced Hg oxidation and removal of Hg by a particulate control device (PCD) have been observed. When about 3%–5% (Btu basis) TDF was cofired with coal at the power plant, measurements showed that the average PCD inlet Hg speciation was 55% particulate bound, 38% oxidized, and 6.4% elemental. Without carbon injection to the PCD, the natural Hg capture efficiency of the PCD was 49%. Furthermore, a carbon injection rate of 24 kg carbon/million m^3 flue gas resulted in a 91% total Hg capture efficiency at the PCD. These field test results indicate that the TDF cofiring has the effect of changing the speciation of Hg at the inlet to the PCD that facilitates Hg collection at the PCD.

Since 1995, DOE has supported development of a new concept in particulate control called the AHPC (19). The AHPC has been licensed to W.L. Gore & Associates, Inc., and is now marketed as the *Advanced Hybrid™* filter by Gore. The *Advanced Hybrid™* combines the best features of ESPs and baghouses in a unique configuration, providing major synergism between the two collection methods, both in the particulate collection step and in the transfer of dust to the hopper. The *Advanced Hybrid™* provides ultrahigh collection efficiency, overcoming the problem of excessive fine-particle emissions with conventional ESPs, and it solves the problem

of reentrainment and re-collection of dust in conventional baghouses. The *Advanced Hybrid™* appears to have unique advantages for Hg control over baghouses or ESPs as an excellent gas-solid contactor. The *Advanced Hybrid™* technology can be a very cost-effective retrofit technology for plants with existing ESPs.

EXPERIMENTAL

Objective and Goals

The goal of this work is to develop advanced, innovative mercury control technologies to reduce mercury emissions by 50% to 90% in flue gases typically found in ND lignite-fired power plants at costs of one-half to three-fourths of current estimated costs. Power plants firing ND lignite produce flue gases that contain >85% elemental mercury, which is difficult to collect. The specific objectives are focused on determining the feasibility of the following technologies: mercury oxidation for increased mercury capture in dry scrubbers and the use of mercury adsorbents within a baghouse.

PLANNED SCOPE OF WORK

Task 1 – Mercury Control Enhancement for Unscrubbed Systems Equipped with ESPs

This task will evaluate and further the ability to control Hg emissions in lignite-fired power systems equipped with an ESP, as well as provide valuable information for enhancing Hg control in other unscrubbed systems. Testing will be performed using sorbent injection on the EERC's particulate test combustor (PTC) equipped with an ESP to evaluate Hg sorbent effectiveness in coal combustion flue gases.

This task will include testing for a full week with up to two ND lignite coals with one activated carbon and the ADA-amended silicate. In addition, a sorbent enhancement technology developed by ALSTOM Power, Inc., will be used to enhance a sorbent for injection in the flue gas duct upstream of the ESP. During ACI, several additives and sorbent enhancements will be tested to quantify the improvements in Hg removal with each. The initial testing will involve shorter-term screening tests for evaluation of the sorbent enhancement additives (roughly two per day). A final full-day test will be performed to obtain longer-term results on the performance of a selected additive. This final additive will be selected based on performance during screening tests and with consideration of cost, availability, and any issues associated with use in a utility system. Based on the test results, initial economic evaluations will be performed to determine the cost savings per pound of Hg removal in comparison to the baseline case of ACI without additives.

Task 2 – Mercury Oxidation Upstream of Wet and Dry Scrubbers

Task 2.1 – Elemental Mercury Oxidation Additives

Potential Hg^0 oxidation additives will be evaluated using the PTC equipped with the refurbished SDA and AHPC. Pilot-scale testing will involve a ND lignite coal with short-term (1- to 2-hr) screening tests of several oxidation additives including chloride compounds (e.g., sodium chloride, hydrogen chloride, calcium chloride) and potassium iodide, followed by longer-term (8- to 10-hr) evaluations of two or more of the most promising additives. In most cases, the additives will be blended with the coals. Gaseous HCl will be injected into the PTC.

Hg^0 and total Hg levels will be measured on a nearly continuous basis using a continuous mercury monitor (CMM) at the inlet and outlet locations of the SDA. Slaked lime slurry feed and the SDA product solids will be analyzed for Hg content. Additive blend ratios and injection rates will be varied to evaluate the effectiveness of additives to oxidize Hg^0 . Economic analyses will be performed for the additives that are most effective.

Task 2.2 – Sorbent Injection

NORIT Americas Inc., DARCO[®] FGD, and lignite-based activated (steam activated at 800°C, 1472°F) Luscar char (derived from Fort Union lignite) will also be injected upstream of the SDA while burning a ND lignite in the PTC. One of the sorbents will be pretreated with an EERC proprietary material to enhance its sorption capacity. FGD, activated Luscar char, and the pretreated sorbent will be injected in the absence and presence of the most effective Hg^0 oxidation additive identified in Task 2.2. In addition, a proprietary sorbent enhancement technology developed by ALSTOM will be tested. CMMs will be used to measure Hg^0 and total Hg at the inlet and outlet of the SDA during each test. After each test, slaked lime slurry feed and the SDA product solids will be analyzed for Hg and carbon contents.

Task 3 – Field Tests to Determine Impacts of Oxidizing Agents on Mercury Speciation

Task 3.1 – Impacts of Cofiring on Tire-Derived Fuels

The efforts in this subtask involve testing the ability of cofiring TDF with ND lignite to increase the oxidized and particulate forms of mercury at a fluid bed-fired power plant (Montana-Dakota Utilities Heskett Station Unit 2, 85 MW, ESP). Testing will include a baseline run firing 100% lignite at full load and up to 10% TDF (Btu basis). Hg and Cl species levels in the flue gas phase will be measured at the inlet and the outlet of the ESP with and without cofiring the TDF. Coal and TDF will be analyzed for basic proximate, ultimate, sulfur, and ash compositional analysis, Cl, Zn, and Hg. Total Hg collection efficiency of the ESP and the Hg speciation information will be determined.

Task 3.2 – Impacts of Oxidation Catalysts – Coyote Station Slipstream Testing

This task involves testing a Hg oxidation agent. Maghemite combined with very small amounts of HCl has been shown to oxidize Hg^0 in simulated flue gases. Currently, a slipstream reactor to test NO_x reduction catalysts is being installed at Otter Tail Power's Coyote Station in North Dakota under an existing EERC project. In Task 3.2, maghemite will be incorporated into a catalyst matrix by Haldor-Topsoe and placed into the reactor. Small amounts of HCl will be added, and the impact on Hg speciation will be measured across the reactor.

Task 4 – Particulate and Mercury Control for ND Lignites Using the *Advanced Hybrid™* Technology

The task includes reconfiguring the PTC with an ESP followed by the *Advanced Hybrid™* system to simulate a full-scale retrofit system. The single-wire tubular ESP will be operated at slightly reduced power to simulate the first one or two ESP fields in a full-scale system, with a goal of removing approximately 90% of the fly ash. Flue gas exiting the ESP with a reduced fly ash level will be routed to the pilot-scale (200-acfm) *Advanced Hybrid™* unit.

Two sorbents (activated carbon and silicate-based sorbent) will be injected near the *Advanced Hybrid™* inlet. Both continuous and batch injection modes will be tested at a flue gas temperature of 300°F. Specific sorbent injection rates will be determined based on the measured Hg concentration in flue gas. For continuous injection, the feed rate will be varied from 2500–12,000 lb sorbent/lb Hg, and for batch injection the ratio will be set at 6000:1. The sorbent that shows the best performance will be tested at a higher flue gas temperature of 400°F both in continuous and batch injection modes. Mercury CMMs will be used to measure Hg^0 and total Hg vapor at the ESP inlet, *Advanced Hybrid™* inlet, and *Advanced Hybrid™* outlet. Mercury sampling with the Ontario Hydro (OH) method will be conducted to provide Hg species information, dust loading, and particulate collection efficiencies for the retrofit *Advanced Hybrid™* unit. EPA Method 26A samples will be carried out at the *Advanced Hybrid™* inlet to determine the chloride level in flue gas entering into the *Advanced Hybrid™* unit. Results from the tests will be reduced, compiled, interpreted, and reported. Mercury removal efficiencies for both sorbents will be calculated, compared, and reported across the ESP, the *Advanced Hybrid™*, and the ESP–*Advanced Hybrid™*.

Task 5 – Field Testing of Sorbents and Gore Technology

This task will test how effectively Hg can be captured by using a sorbent-based technology and the recently announced Gore technology in conjunction with a pulse-jet baghouse (PJBH) at a power plant in North Dakota. The Gore technology consists of a proprietary baghouse insert downstream of the FF that has shown a high potential to control Hg. An existing baghouse will be skid-mounted and transported to a power plant in North Dakota and connected in slipstream fashion to allow for testing actual flue gases. Additions to the existing baghouse unit for remote field application will include a control room for remote operation, piping and flanges for connection to plant ductwork, a variable-speed fan, and a sorbent injection system for Hg control. The PJBH can operate for much longer periods of time than can the pilot-scale AHPC.

The skid-mounted baghouse will be installed downstream of an existing PCD such as an ESP at a ND power plant. The Gore technology will be installed, tested, and monitored for Hg capture effectiveness for 4 months. For these measurements, EPA Method 101A will be used to determine the total Hg (only) removed across the baghouse system.

RESULTS AND DISCUSSION

Task 1 – Mercury Control Enhancement for Unscrubbed Systems Equipped with ESPs

During this quarter, hardware construction and modification were completed to the pilot-scale system equipped with an ESP followed by an *Advanced Hybrid*TM filter unit. Several pilot-scale tests were planned and performed. The purposes of the tests were to demonstrate mercury removal by sorbent injection combined with various oxidizing additives to simulate an unscrubbed ESP system. Several key parameters such as sorbent, oxidation additive, injection rate and operating temperature were being evaluated.

Table 1 summarizes the test matrix for the ESP test configuration. Four DARCO[®] FGD-based sorbents including normal DARCO[®] FGD, Cl-treated FGD, EERC-treated FGD, and ALSTOM enhanced FGD were injected upstream of the ESP to determine their effectiveness for mercury removal across the ESP. ADA Technologies Amended SilicateTM was not tested because ADA was unable to provide the sorbent because of manufacturing problems. Additionally, different additives were injected into the coal to examine their impact on sorbent performance for mercury capture. Two CMMs were set up at the ESP inlet and outlet to monitor Hg vapor concentrations continuously throughout the 10-day test. A total of eight OH samples were taken to verify CMM measurement and performance of the sorbents with additive injection.

The pilot-scale test was started on September 8, 2003, and completed on September 19, 2003. Preliminary results, as shown in Figure 4, demonstrate effective mercury removal across the ESP when sorbent injection was combined with mercury oxidant addition to the coal. The experimental data from these test runs are being reduced and interpreted. Preliminary results are attached in a confidential appendix for limited distribution. Once the data have been reviewed and all the data incorporated, the finalized results will be presented in the next quarterly report.

Task 2 – Mercury Oxidation Upstream of Wet and Dry Scrubbers

Task 2.1 – Elemental Mercury Oxidation Additives

The additives to be tested were determined. Based on previous pilot-scale testing results of ESP mercury removal effectiveness, three different sorbents (DARCO[®] FGD activated carbon, supplied by NORIT Americas, Inc.; an EERC-treated DARCO[®] FGD; and Amended SilicateTM, developed by ADA Technologies, Inc.) and three additives (NaCl, CaCl₂, and a third additive that the EERC is currently using and is assessing the intellectual property issues for, to be referred to as Additive C) will be evaluated.

Table 1. Test Matrix of Mercury Control for an Unscrubbed System Equipped with ESP

Sorbent:	DARCO [®] FGD, Cl-treated FGD, EERC-treated FGD, ALSTOM enhanced sorbent	
Additive:	NaCl(s), CaCl ₂ (a), Zn, furnace Additive C(s)	
	DARCO [®] FGD	15, 50, 105, 150 g/hr
	Halogen-treat	10, 15, 25 g/hr
	ALSTOM	7, 9, 14 g/hr
Injection Rate:	NaCl (s)	20, 40, 60 g/hr
	CaCl ₂ (a)	10, 100 g/hr
	Furnace Additive C	10, 40 g/hr
	Zn (s)	40, 60 g/hr

Task 2.2 – Sorbent Injection

Originally, we proposed to test a char produced from Ravenscrag lignite (Bienfait mine, Saskatchewan, Canada) by Luscar Ltd. as a sorbent for mercury control. Alternatively, we have decided to test an EERC-treated DARCO[®] FGD activated carbon because Luscar char is not as readily available as DARCO[®] FGD and previous testing on our bench- and pilot-scale facilities indicated that Luscar char mercury removal effectiveness was similar to DARCO[®] FGD (20). DARCO[®] FGD and Additive C injection test results from our pilot-scale (580-MJ/h, or 550,000-Btu/h) combustion system equipped with an ESP suggest that the EERC-treated DARCO[®] FGD will effectively capture mercury.

Task 3 – Field Tests to Determine Impacts of Oxidizing Agents on Mercury Speciation***Task 3.1 – Impacts of Cofiring on Tire-Derived Fuels***

The activities this quarter involved finding a supplier for the TDFs. The testing is scheduled to begin this spring at Montana-Dakota Utilities Heskett Station. Conversations have begun with Montana-Dakota Utilities. A field trip is being planned to the Heskett Station. This activity will begin in the next month.

Task 3.2 – Impacts of Oxidation Catalysts – Coyote Station Slipstream Testing

The EERC is working with Haldor-Topsoe to formulate a catalyst for this activity. The reactor is installed at the Coyote Station under a current contract. The testing is scheduled to begin in January 2004.

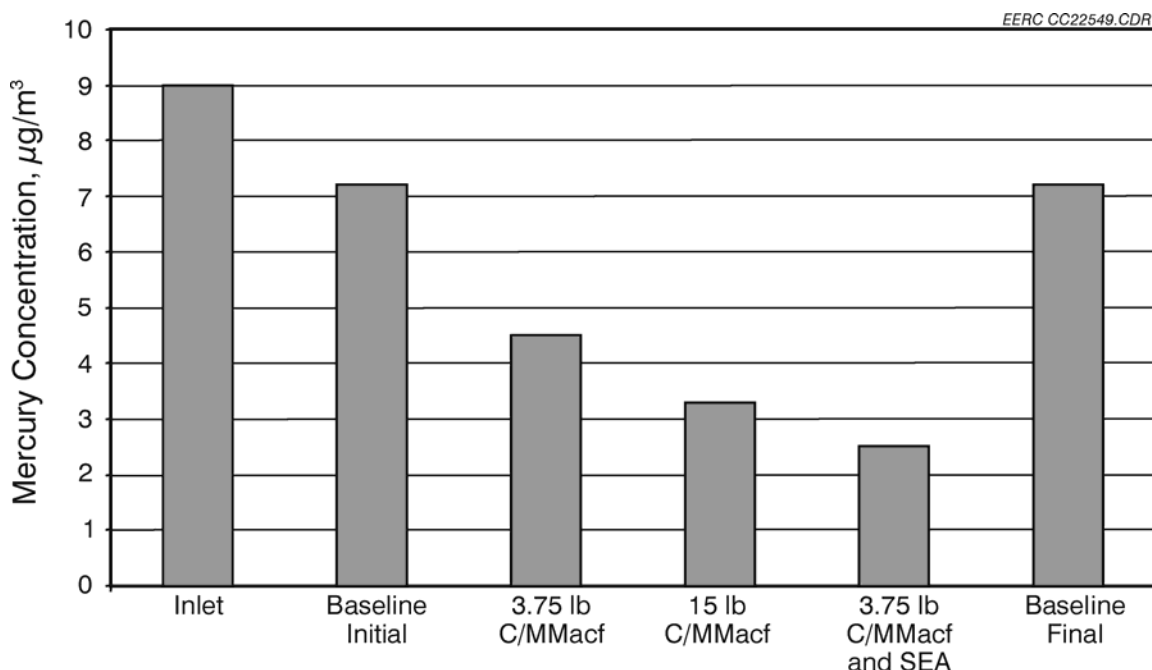


Figure 4. Mercury emission at the ESP outlet with sorbent and additive addition.

Task 4 – Particulate and Mercury Control for ND Lignites Using the AH Technology

As part of the effort to obtain information on possible mercury control technology options for ND lignite-fired power plants, Tasks 1 and 4 involving several pilot-scale tests were performed during the 10-day test. With respect to this task, the purpose of the tests was to demonstrate mercury removal by sorbent injection combined with various oxidizing additives to simulate a retrofit *Advanced Hybrid*TM filter system. During this quarter, hardware construction and modification were completed to the pilot-scale system equipped with an ESP followed by an *Advanced Hybrid*TM filter unit. A 10-day test was performed with several key parameters such as sorbent, additive, injection rate, and operating temperature being evaluated.

Table 2 shows the test matrix for this task. The ESP was operated at less than optimal conditions to simulate a retrofit application of the *Advanced Hybrid*TM filter. The flue gas exiting the ESP with low dust loading was then introduced to the *Advanced Hybrid*TM unit while sorbent was injected upstream the *Advanced Hybrid*TM filter unit. Two injection modes, continuous and batch injection, were evaluated at different operating temperatures of 300° and 400°F, respectively. The additives were also added to the coal to examine their effect on sorbent performance. Two CMMs were used to measure mercury vapor concentrations at the *Advanced Hybrid*TM filter inlet and outlet. OH sampling was performed to verify the results. To achieve the same level of mercury control, less sorbent was needed for the retrofit *Advanced Hybrid*TM filter system than shown here for the ESP because of the enhanced contact between sorbent and mercury on the filter bag surface. Activities are under way to reduce and interpret the experimental data. Preliminary results are attached in a confidential appendix. Final results will be presented in the next quarterly report.

Table 2. Test Matrix of Mercury Control for a Retrofit *Advanced Hybrid*TM Filter System

Sorbent:	DARCO [®] FGD, regenerated FGD
Additive:	NaCl (s), Furnace Additive C
Sorbent Injection Mode:	Continuous and batch injection
Temperature:	300° and 400°F
Injection Rate:	DARCO [®] FGD 5, 11, 22, 44 g/hr
	Regenerated FGD 20 g/hr

Task 5 – Field Testing of Sorbents and Gore Technology

The baghouse design was completed and modifications to the existing baghouse chamber were nearly completed during this quarter. The baghouse will be mounted on a flatbed trailer for ease of transport and installation at any location. The trailer was purchased and is being modified so that the baghouse will remain stable during long-term operation at a host utility. Purchase orders for the fan, control room, piping, and auxiliary equipment have been issued, and the majority of the equipment is on-site.

The field test plan was completed. Test plan objectives are:

- To demonstrate that mercury can be effectively captured by injecting a sorbent upstream of a slipstream baghouse drawing flue gas at the exit of Basin Electric's Leland Olds Unit 1 ESP.
- To demonstrate that mercury can be effectively captured by placing the Gore technology within a slipstream baghouse, drawing flue gas at the exit of Basin Electric's Leland Olds Unit 1 ESP.
- To compare the mercury removal performance of a sorbent-based technology to the Gore technology.

Testing will be performed at Basin Electric's Leland Olds Unit 1 to determine how effectively mercury can be captured by using a sorbent-based technology and the Gore technology in conjunction with a baghouse. A trailer-mounted baghouse will be transported to the Leland Olds Station and connected in slipstream fashion to allow for testing "real" flue gases under actual operating conditions.

The slipstream baghouse chamber is designed to accommodate twelve 6-inch fabric filters, with bag lengths up to 12 feet. This equates to approximately 226 ft² of filtration area. It is assumed that Gore will provide, at no charge to the project, new bags and cages that are appropriate to meet the objectives of the test. To connect the slipstream baghouse to the outlet of the ESP at Leland Olds Unit 1, two separate 10-inch flanges will be required, one at the immediate exit of the ESP and the other downstream of this location, but upstream of the

induced draft (ID) fan. It is assumed that Basin Electric will provide these connections at no charge to the project.

A variable-speed blower is provided as part of the mobile unit and is capable of drawing between 450 and 2700 acfm of flue gas ($\approx 300^{\circ}\text{F}$) through the slipstream device for a filter face velocity between 2 and 12 ft/min. The blower will be controlled at a rate sufficient to draw gases at or near the maximum system flow of 2700 acfm for all test conditions. An 8-inch baghouse bypass line will be utilized as a flow control mechanism. Flow control will be provided by utilization of an orifice meter on the baghouse effluent stream with a flow control valve inserted in the 8-inch bypass line. Utilization of the bypass line allows for a constant draw of flue gas, maintaining isokinetic flow at the inlet nozzle for all test conditions. In addition, pipe velocities will be maintained near 75 ft/sec for all test conditions, preventing dropout of fly ash particles. The baghouse chamber will utilize between 1 and 3 inlet ports (5-inch diameter), depending upon test conditions (see Figures 5–7). Gases will be drawn from an 8-inch header at the baghouse inlet. The baghouse chamber and inlet piping runs will be insulated, with heat-traced lines used to maintain temperatures above a specified minimum, assumed to be 280°F . Pictures of the portable baghouse can be seen in Figures 5–8.

Tentatively, the EERC would transport the mobile unit to the Leland Olds Station early next spring. Prior to this, Gore would provide appropriate bags, cages, and their mercury control technology. Basin would provide the following:



Figure 5. Baghouse chamber and support structure.



Figure 6. Baghouse top and exhaust header.



Figure 7. Baghouse extension showing inlet ports.

EERC CC22556.CDR



EERC CC22557.CDR

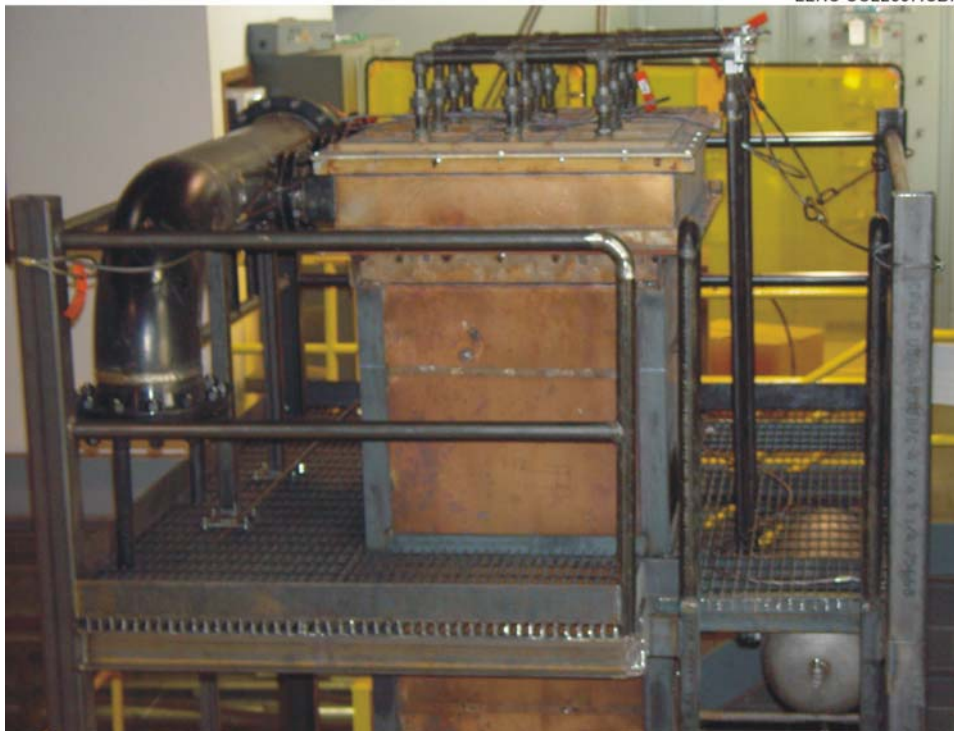


Figure 8. Completed baghouse.

- Access to the plant
- Assistance and cooperation from plant personnel during planning and while on-site
- Assistance from plant personnel to adjust valve positions, if required, and change out ash collection barrels between site visits
- A site location with level grade to place trailer and mobile unit
- A 10-inch duct connected near the ESP outlet
- A 10-inch return duct connected upstream of the ID fan
- An adequate source of low-voltage (480-V) 3-phase electricity (≈ 60 amps)
- Approximately 120 amps of 3-phase (120-V) electricity
- An adequate source of house air ($\frac{3}{8}$ – $\frac{1}{2}$ -inch line)
- A dedicated phone line for remote control of the system

The EERC would need approximately 1 week for setup and shakedown testing before testing could begin. Once set up, the EERC would begin testing of the Gore technology. The proposed plan will test the Gore technology first followed by sorbent injection tests. This will prevent any possible confounding effects due to the activated carbon. During the first 2 months of testing, the Gore technology will be installed, tested, and monitored for mercury capture effectiveness. The first test will take place during the installation of the Gore technology and before any sorbent is injected and will last approximately 1 week. Inlet and outlet mercury measurement will be taken using the OH procedure during the first week only. These measurements should provide baseline mercury values as well as some indication of particulate matter loading. A limited number of OH samples will be taken to verify performance of the Gore technology. Following the first week of testing, mercury sampling will be conducted at 1 month, and at the end of 2 months, assuming that the Gore technology continues to show good mercury capture throughout the test period. For these measurements, to save cost, Method 101A will be used to determine the total mercury (only) removed across the baghouse system. CMMs at the inlet and outlet will also be used for a 1-week interval at the beginning and end, along with the 101A sampling activities. At the end of the 2-month test period, the Gore technology will be removed. Subsequently, the EERC trailer-mounted sorbent injection system will begin injecting the DARCO[®] FGD activated carbon. This test is planned to last approximately 1 week and will involve injecting the sorbent at various rates at the inlet to the trailer-mounted baghouse. Temperature will be maintained above a specified minimum set point as described above. During the weeklong test, air/cloth ratios will be varied to achieve face velocities between 4 and 12 ft/min. Sorbent injection will be performed using a self-contained feed system, injecting sorbent into the 8-inch header at the entrance to the baghouse at an expected rate of 2–10 lb/MMft³, depending on level of mercury reduced. Daily activities are outlined below:

- Days 1 and 2 – Face velocity maintained at 8 ft/min (1810 acfm). Sorbent injection will be varied to achieve 80%–90% mercury removal.
- Days 3 and 4 – Face velocity maintained at 4 ft/min (905 acfm). Sorbent injection rate set at same rate as established under the test performed during Days 1 and 2.
- Days 4 and 5 – Face velocity maintained at 12 ft/min (2714 acfm). Sorbent injection rate set at same rate as established under the test performed during Days 1 and 2.

During this test period, CMMs will be operated and limited OH sampling will be conducted. Standard quality assurance/quality control (QA/QC) practices will be followed for all mercury-sampling activities. A field spike and blank will be taken during each sampling period and all samples will be done in triplicate.

Results from the tests will be reduced, compiled, interpreted, and reported. Mercury removal efficiencies for both the sorbent-based and Gore technologies will be calculated, compared, and reported. Data available from mercury CMMs and OH will be corrected and reported along with other data provided by the plant.

FUTURE WORK – NEXT QUARTER

Work in the upcoming quarter will involve data reduction of existing experimental data related to the ESP, data collection from the test runs using the wet and dry scrubbers, and continued construction of the portable baghouse unit in preparation for field testing. Specifically:

- The experimental data from test runs performed under Tasks 1 and 4 will be further reduced and interpreted. Ash samples from the pilot-scale activities will be analyzed. Discussion of the results will be included in the next quarterly.
- The spray dryer is anticipated to be initially operated during November 3–12, 2003. Mercury control testing is anticipated to occur during December 8–11, 2003, and then again for a 2- or 3-day period. Based on previous pilot-scale testing results of ESP mercury removal effectiveness, three different sorbents (DARCO[®] FGD activated carbon, supplied by NORIT Americas, Inc.; an EERC-treated DARCO[®] FGD; and Amended Silicate[™], developed by ADA Technologies, Inc.) and three additives (NaCl, CaCl₂, and Additive C) will be tested at different injection and addition rates, respectively. The mercury removal efficiency of the spray dryer–baghouse combination will be determined by analyzing mercury at the spray dryer inlet and baghouse outlet using CMMs and the OH method.
- Construction activities will continue next quarter to complete the installation of the baghouse and auxiliary equipment on the trailer bed.

An updated milestone chart is presented in Figure 9.

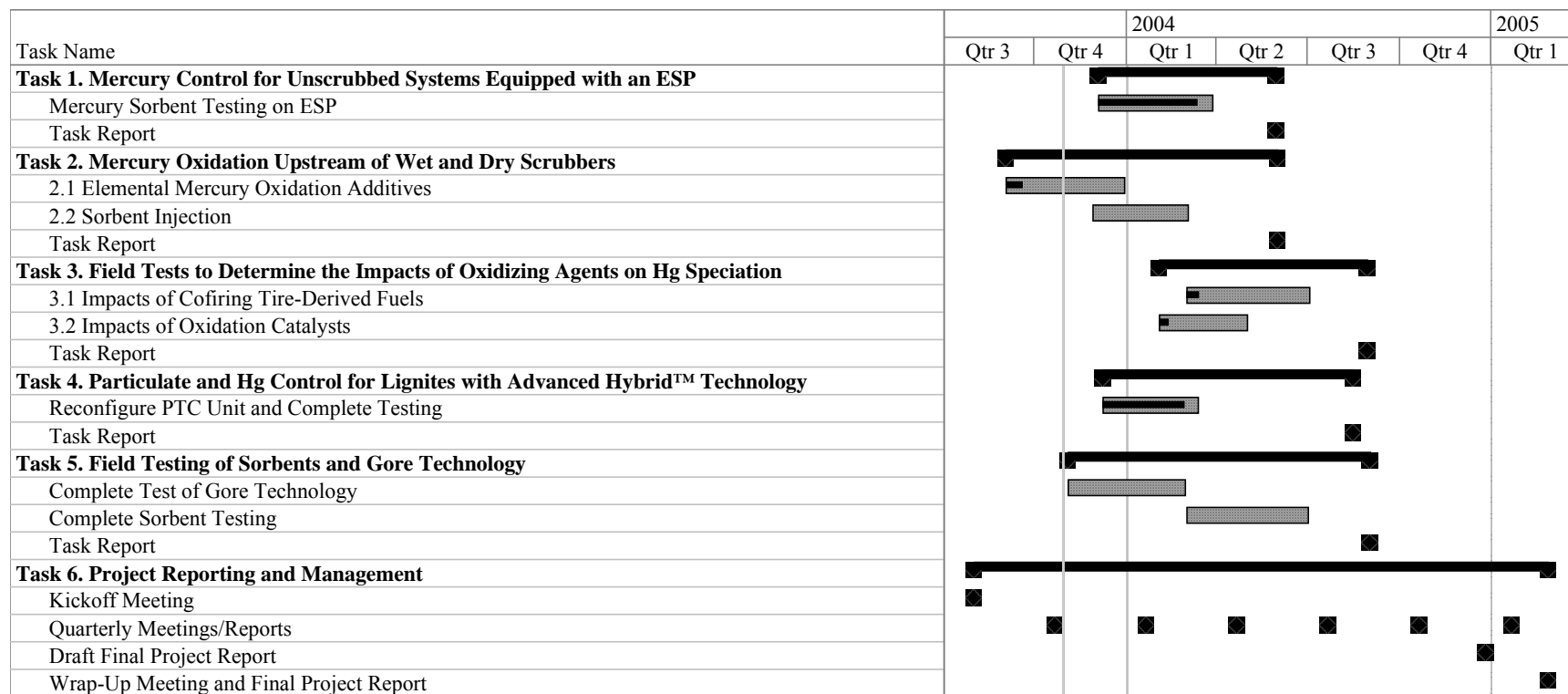


Figure 9. Milestone chart.

REFERENCES

1. Pavlish, J.H.; Holmes, M.J.; Benson, S.A.; Crocker, C.R.; Galbreath, K.C. Mercury Control Technologies for Utilities Burning Lignite Coal. In *Proceedings of Air Quality III, Mercury, Trace Elements, and Particulate Matter Conference*; Arlington, VA, Sept 10–12, 2002; Energy & Environmental Research Center: Grand Forks, ND, 2002.
2. Chang, R.; Strohfus, M. *The Evaluation of Chemical Additives for Mercury Emission Control at Great River Energy*; Final Report to the North Dakota Industrial Commission; Jan 2003.
3. Felsvang, K.; Gleiser, R. Juip, G.; Nielsen, K.K. Activated Carbon Injection in Spray Dryer/ESP/FF for Mercury and Toxics Control. *Fuel Process. Technol.* **1994**, 39, 417–430.
4. Pavlish, J.H.; Sondreal, E.A.; Mann, M.D.; Olson, E.S.; Galbreath, K.C.; Laudal, D.L.; Benson, S.A. Status Review of Mercury Control Options for Coal-Fired Power Plants. *Fuel Process. Technol.*, **2003**, in press.
5. Carey, T.R.; Hargrove, O.W.; Richardson, C.F.; Chang, R.; Meserole, F.B. Factors Affecting Mercury Control in Utility Flue Gas Using Activated Carbon. *J. Air Waste Manage. Assoc.* **1998**, 48, 1166–1174.
6. Dunham, G.E.; Olson, E.S.; Miller, S.J. Impact of Flue Gas Constituents on Carbon Sorbents. In *Proceedings of the Air Quality II: Mercury, Trace Elements, and Particulate Matter Conference*; McLean, VA, Sept 19–21, 2000; Paper A4-3.
7. Olson, E.S.; Sharma, R.K.; Miller, S.J.; Dunham, G.E. Identification of the Breakthrough Oxidized Mercury Species from Sorbents in Flue Gas. In *Proceedings of the Specialty Conference on Mercury in the Environment*; Minneapolis, MN, Sept 15–17, 1999; pp 121–126.
8. Pavlish, J.H.; Holmes, M.J.; Benson, S.A.; Crocker, C.R.; Galbreath, K.C. Mercury Control Technologies for Utilities Burning Lignite Coal, In *Proceeding of Air Quality III, Mercury, Trace Elements, and Particulate Matter Conference*; Sept 9–12, 2002.
9. Bustard, J.; Durham, M.; Starns, T.; Lindsey, C.; Martin, C., Schlager, R.; Bladrey, K. Full- Scale Evaluation of Sorbent Injection for Mercury Control on Coal-Fired Power Plants, In *Proceeding of Air Quality III: Mercury, Trace Elements, and Particulate Matter Conference*, Sept 9–12, 2002.
10. Sjostrom, S.; Richardson, C.; Chang, R. *Evaluation of Mercury Emissions and Control Options for Great River Energy*; Final Report for North Dakota Industrial Commission, June 2001.

11. Liu, W.; Vidic, R.D.; Brown, T.D. Optimization of Sulfur Impregnation Protocol for Fixed-Bed Application of Activated Carbon-Based Sorbents for Gas-Phase Mercury Removal. *Environ. Sci. Technol.* **1998**, *32*, 531–538.
12. Ghorishi, S.B.; Kenney, R.M.; Serre, S.D.; Gullett, B.K.; Jozewicz, W.S. Development of a Cl-Impregnated Carbon for Entrained-Flow Capture of Elemental Mercury. *Environ. Sci. Technol.* **2002**, *36*, 4454–4459.
13. Dunham, G.E.; Miller, S.J.; Laudal, D.L. *Investigation of Sorbent Injection for Mercury Control in Coal-Fired Boilers*; Final Report for EPRI and DOE; Energy & Environmental Research Center: Grand Forks, ND, Sept 1998.
14. Laumb, J.D.; Benson, S.A.; Olson, E.S. X-Ray Photoelectron Spectroscopy Analysis of Mercury Sorbent Surface Chemistry In *Proceedings of the Air Quality III: Mercury, Trace Elements, and Particulate Matter Conference*; Arlington, VA, Sept 9–12, 2002; Energy & Environmental Research Center: Grand Forks, ND, 2002.
15. Benson, S.A.; Olson, E.; Crocker, C.; Pavlish, J.; Holmes, M. Mercury Sorbent Testing in Simulated Low-Rank Coal Flue Gases. In *Proceedings of the 6th Electric Utilities Environmental Conference*; Jan 27–30, 2003.
16. Lovell, J.; Butz, J.; Broderick, T. Ultimate Fate of Mercury Sorbents. In *Proceedings of the Air Quality III: Mercury, Trace Elements, and Particulate Matter Conference*; Arlington, VA, Sept 9–12, 2002; Energy & Environmental Research Center: Grand Forks, ND, 2002.
17. Laudal, D.L.; Thompson, J.S.; Pavlish, J.H. Use of Continuous Mercury Monitors at Coal-Fired Utilities. In *Proceedings of the Air Quality III: Mercury, Trace Elements, and Particulate Matter Conference*; Arlington, VA, Sept 9–12, 2002; Energy & Environmental Research Center: Grand Forks, ND, 2002.
18. Zygarlicke, C.J.; Galbreath, K.C.; Toman, D.L. Coal Combustion Mercury Transformations. Presented at the Air Quality II: Mercury Trace Elements, and Particulate Matter Conference, McLean, VA, Sept 19–21, 2000.
19. Miller, S.J.; Zhuang, Y.; Olderbak, M.R. *Mercury Control with the Advanced Hybrid Particulate Collector*. Technical Progress Report; Energy & Environmental Research Center: Grand Forks, ND, Nov 2002.
20. Pavlish, J.H.; Holmes, M.J.; Benson, S.A.; Crocker, C.R.; Olson, E.S.; Galbreath, K.C.; Zhuang, Y.; Pavlish, B.M. Mercury Control Technologies for Electric Utilities Burning Lignite Coal. Draft Final Report [Feb 1, 2002 – March 31, 2003] for U.S. Department of Energy National Energy Technology Laboratory Cooperative Agreement No. DE-FC26-98FT40321; Energy & Environmental Research Center: Grand Forks, ND, April 2003.